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Thinking ahead for Europe

Policy Uncertainty and International Financial Markets: The Case of Brexit

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Abstract

This study assesses the impact of the uncertainty caused by Brexit on both the UK and international financial markets, for the first and second statistical moments (i.e. on the changes and standard deviations of the respective variables.) As financial markets are by nature highly interlinked, one might expect that the uncertainty engendered by Brexit also has an impact on financial markets in several other countries. By analysing the impact of Brexit on financial markets, we might also gain some insight into market expectations about the magnitude of the economic impact beyond the UK and which other countries might be affected. For this purpose, we first use both the Diebold and Yilmaz (2012) and the Hafner and Herwartz (2008) method to estimate the time-varying interactions between UK policy uncertainty, which is largely is attributed to uncertainty about Brexit, and UK financial market volatilities (second statistical moment) to try to identify the direction of causality among them. Second, we use two other measures of the perceived probability of Brexit before the referendum, namely daily data released by Betfair and results of polls published by Bloomberg. Based on these datasets, and using both panel and single-country SUR (seemingly unrelated regressions) estimation methods, we analyse the Brexit effect on levels of stock returns, sovereign credit default swaps (CDS), 10-year interest rates in 19 predominantly European countries, and those of the British pound and the euro (first statistical moment). We show that Brexit-induced policy uncertainty will continue to cause instability in key financial markets and has the potential to damage the real economy in both the UK and other European countries, even in the medium run. The main losers outside the UK are the 'GIIPS' economies: Greece, Ireland, Italy, Portugal and Spain.

JEL codes: C58, D81, E44, F36, G15

Keywords: Brexit, causality tests, financial instability, pound sterling, uncertainty, spillovers

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Introduction

The majority of British citizens have decided that the UK should leave the European Union (EU) in the near future. Although the referendum result was very close, the leave campaign, led by Messrs Johnson and Farage, succeeded. Quite apart from the consequences for the UK, this can be seen as a political disaster for the EU, as for the first time ever a member state is actually going to leave. Numerous institutions, academics, and politicians have warned of negative economic effects for both the UK and Europe, arguing that Britain's departure will generate a 'lose-lose' situation.[1]

As Brexit can surely be regarded as the most significant political event in the first half of 2016, poll updates, and the actual result on 24th of June, greatly affected international financial markets (European Commission, 2016). Since financial markets are highly interlinked in general and several countries apart from the UK might be negatively affected, it is legitimate to expect that Brexit has an impact on financial markets beyond the UK. By analysing the impact of Brexit on financial markets, we might also gain an insight into market expectations of the magnitude of the economic impact beyond the UK, and which other country might be most affected.

In our view, this topic is too complex to simply check for trade and financial linkages to determine which countries will be most affected, partly because the institutional framework of the EU and the euro area has generated additional dependencies between countries. According to the dividend discount model (Gordon and Shapiro, 1956), *expectations about future effects* on the real economy generated by Brexit will immediately affect stock returns and several other financial market variables. We therefore give a short overview of the possible effects of enduring Brexit uncertainty on the real economy of the UK and other countries, particularly the remaining EU countries. Of course, any increase in policy uncertainty itself can be expected to affect financial markets as well. Among others, this kind of uncertainty typically leads to option value effects, i.e. a 'wait-and-see attitude' towards investment-type decisions.

We also need to address the discussion in the literature about whether and why volatility means uncertainty. In the empirical part of this paper, we use actual asset price changes rather than just unanticipated ones, but on a monthly horizon, the anticipated change is

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[1] For a survey of related arguments see, for instance, London School of Economics (2016). Fears about Brexit are not accidental; they have been indicated by systematic differences in monetary policies on both sides of the Channel. See D'Addona and Musumeci (2011).

usually close to zero. Hence, actual and unanticipated changes should give the same results. We therefore feel that it is legitimate to strictly follow Belke and Gros (2002), for instance, and to use historical volatilities (i.e. the standard deviation) or generalized autoregressive conditional heteroscedasticity ((G)ARCH) estimates as measures of uncertainty.

Our interest is in the direction of spillovers into policy uncertainty and financial market volatilities in the UK itself. Our second research question is whether we can expect contagion from the UK to other countries, through the political and institutional channel, for instance, ther EU member states also asking "Why can't we also be exceptions?" For this purpose, we also empirically check for the spillovers of Brexit uncertainty onto a variety of asset classes in international financial markets (Begg, 2016).

The remainder of this paper is organised as follows: the next section provides a brief overview of the possible effects of enduring Brexit uncertainty on the UK and the real economy of other countries. In section 2, we investigate the effect of Brexit on the UK's financial market volatilities. Our main focus is both on the Diebold and Yilmaz (2009) and the Hafner and Herwartz (2004, 2008) method to estimate spillovers of policy uncertainty onto financial volatility (second statistical moment). Moreover, we try to identify the direction of causality among them. In section 3, we empirically assess the impact of Brexit on international financial markets and a variety of asset categories (first statistical moment), employing both panel and single-country SUR estimation methods. Section 4 concludes.

1. Possible effects of enduring Brexit uncertainty on the real economy of the UK and other countries

Leaving the EU can be expected to have huge implications for the British economy through the following channels: trade in goods and services, investment, immigration, productivity and fiscal costs.[2] As Brexit is a political novelty, it is very difficult to estimate the effect of each channel and the overall impact on the British economy. Uncertainty around the effects is further increased by the fact that the British government and the EU will have to completely re-evaluate their political and economic relationship. Furthermore, the British government will have to make significant political decisions e.g. regarding prudential and regulatory laws.

As a starting point of our empirical study, it is important to note that, apart from a weaker pound and lower UK interest rates, the referendum itself did not cause much of an enduring impact (Gros, 2016). Financial markets tumbled for a couple of weeks after the referendum, but have recovered since. Consumer spending remains rather stable. Even more surprisingly, investment has remained relatively constant, in spite of significant uncertainty about Britain's future trade relations with the EU. So, have the costs of Brexit been overblown? One might argue that "(t)he United Kingdom's vote to 'Brexit' the EU is on course to become the year's biggest non-event" (Gros, 2016). But how to explain the current lack of impact? It may just be because Brexit has not yet happened (Begg, 2016). A major economic impact of Brexit can thus still not be ruled out in the future. Furthermore, CEIC Data for July 2016 already

[2] In the following, we do not discuss the various arguments surrounding immigration and fiscal costs. For a broad survey on the potential economic impacts of Brexit, see IMF (2016).

indicates that business and consumer confidence has fallen by about 4% and 12% respectively.[3]

Regarding the trade channel, the most important aspect is the fact that the UK will most probably *lose its access to the European single market*. The EU is the UK's most important trading partner. Nearly half of UK exports in goods and services are delivered into the EU (approx. 13% of UK GDP in 2014). Apart from an absence of tariffs, the single market guarantees the principle of mutual recognition and the so-called 'single passport' – a system that allows services operators legally established in one member state to provide their services in other member states without further authorisation requirements (EC, 2016). Non-European firms can therefore set up headquarters in the UK to access the single market and offer their services in the entire EU. The financial sector is a key component of the UK economy, with London being one of the largest financial centres in the world.[4] Financial services generate about 8% of national income (the EU average is nearly 5%), trade in financial services alone was about 3% of the nominal GDP in 2014 (the EU average is nearly 1%), and 40% of total financial service exports are exported to the EU. The financial centre of London would lose out significantly in terms of attractiveness as it could no longer generate access to this European single market.[5]

The effects will crucially depend on the results of negotiations between the UK and EU about their future economic (and political) relationship. If the UK keeps its access to the single market, the effects via trade might be small.6 However, in the worst-case scenario, the trade relationship defers to the WTO framework, if no alternative agreement is reached (Blockmans and Emerson, 2016). In that event, it is highly probable that trading links between the UK and the EU will be weakened or even disrupted, generating decreases in UK income from exports.[7] The effects are not only limited to trade relationships with the EU. First, the UK will not be part of future FTAs (free trade agreements), which are currently negotiated between the EU and countries like Brazil, China, and the USA. Second, the UK will no longer be subject to the FTAs that have been successfully negotiated by the EU and will therefore experience further limitations in trading possibilities.[8] Whether the UK can offset the decrease in trade with the EU and corresponding national income by focusing its trade ambitions on other (faster-growing) markets is questionable. While it might be possible for the UK to negotiate new FTAs, it will probably take longer than its withdrawal from the EU under Article 50, thereby generating a potential disruption of trade as trade relationships with those countries will default on WTO rules. Furthermore, it appears questionable

[3] See https://www.ceicdata.com/en/blog/ceic-macro-dashboard-july-2016.

[4] The UK is the world leader in fixed-income and derivatives transactions and far ahead of EU peers in private equity, hedge funds, and cross-border bank lending (Bank of England, 2015). The UK's insurance industry is the largest in Europe and the third largest in the world.

[5] Several asset managing companies (e.g. M&G, Columbia Threadneedle) and several banks have expressed their intentions to move staff out of the UK capital and/or set up fund ranges in neighbouring EU countries for fear of being locked out of European fundraising (FT, 2016). This 'escape' from the UK is not limited to the financial sector; Vodafone has already announced that it might move its headquarters if the UK leaves the single market (WSJ, 2016).

[6] An alternative might be the Norwegian model (EEA) or Swiss model.

[7] This view is backed by empirical results underscoring the finding that the reduction in trade barriers due to EU membership has increased UK incomes (Crafts (2016), Campos et al. (2014)).

[8] For an overview, see Van der Loo and Blockmans (2016).

whether the UK can simply substitute other exports markets for European markets, especially in the short to medium term.

The UK has been subject to large FDI (foreign direct investment), especially from EU countries – almost half of total FDI. It is reasonable to assume that the amount of FDI coming from the EU will be adversely affected as a strong link between EU membership and inward FDI has been documented by several studies (Fournier et al. 2015, Bruno et al. 2016, 2016a, Dhingra, Ottaviano and Sampson, 2015). Furthermore, FDI from outside the EU might decrease as well, as the UK can no longer provide a gateway to the single market. According to the Office for National Statistics (ONS), the average flow of inward FDI has been about 5% of GDP between 1999 and 2015. As a financial centre, the UK is dependent on inward FDI and financial flows in general. If London loses its status as a global financial centre, FDI will decrease and so too, in all probability, will consumption and investment.

Critics of the EU argue that many regulations imposed by EU institution generate costs, are inflexible and limit business opportunities for companies. OpenEurope (2015) argues that benefits from deregulation might compensate trade losses. Yet the space for further deregulation appears to be limited in the UK. According to the OECD, the UK ranks at a level with the USA with regard to product market liberalisation. Labour market flexibility is relatively high – especially compared with European countries like France and Germany. It is therefore questionable whether this limited remaining deregulation potential will boost productivity enough to offset trade losses. The LSE (2013) concludes that the UK is already deregulated and a more skilled workforce and better infrastructure are more potent sources of further productivity.

Figure 1 represents a survey of studies that attempt to quantify the long- and short-term effects of Brexit, for 2018. According to the IMF (2016), under their adverse scenario, the UK might experience a steep drop in GDP in 2017, causing a severe recession. While some studies even indicate positive (long-term) effects (Minford, 2016, OpenEurope, 2015, Mansfield, 2014), the majority of studies indicate considerable negative short- and long-term effects. Differences in the results of studies presented in Figure 1 can mainly be traced back to differing assumptions in the underlying economic model; a different emphasis on specific channels; and different projections about the future economic relationship between the EU und the UK. Studies that find that negative effects place more emphasis on negative trade and investment effects.

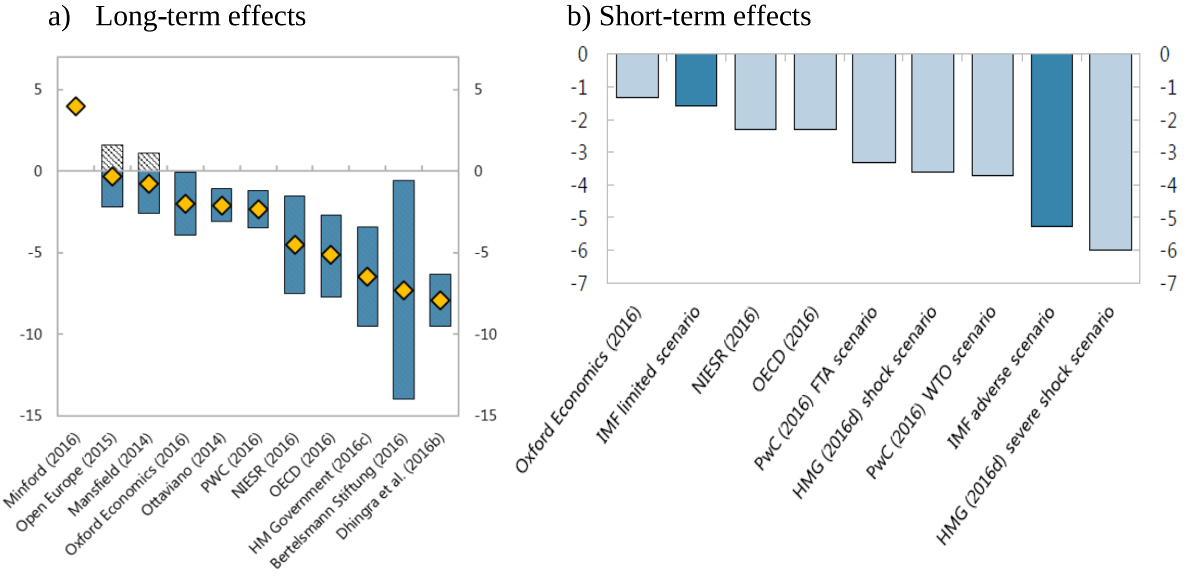
The few studies describing positive net results focus on gains from deregulation and enhanced productivity. The short-term effects (for 2018) of Brexit are uniformly negative, but also vary in magnitude. These studies underline the possibility of a severe recession or at least a decrease in growth. Apart from academic arguments, the monetary and fiscal policies seem to support this view. In July, the decision of the Bank of England to cut its bank rate to 0.25% has been justified by the adverse effects of Brexit on the economy. On the fiscal policy side, the UK's Finance Minister Philip Hammond has made several statements about the possibility of a more aggressive fiscal approach in order to cope with the short-term to mid-term effects of Brexit.[9]

Considering the short-run effects, the Brexit decision in June 2016 caused immediate financial turmoil – stock markets slid in response to the vote in an orderly decline and the

[9] See http://uk.reuters.com/article/uk-britain-eu-economy-hammond-idUKKCN1020O7, and Philip Hammond's most recent budget speech.

British pound suffered major losses. It could take at least two years for the UK to formally leave the 28-nation bloc, and it is unclear how much the country's relationship with the EU will change. This means that markets are likely to remain volatile, at least until it becomes clear what a Brexit scenario means for the UK and for the rest of the EU.[10]

Figure 1. Economic effects of Brexit on the UK GDP



Note: Deviation from baseline (=UK remains in the EU). Short-run values for 2018. The long-term effects are the accumulated effect on GDP (time horizon depends on the individual study, roughly 5 years).
Source: IMF (2016a), p. 24 & 33.

It has already been shown in the literature that during crises and particular political events, financial market volatility generally increases sharply and spills over into markets. Thus, uncertainty about Brexit might not only directly influence shares and exchange markets, but might also trigger increased spillovers across them. Financial instabilities, such as an increase in FX volatilities, pose further potential adverse effects for the economy, implying that firms will postpone new investments and hiring decisions, benefiting from the so-called "option value of waiting" (Belke and Gros, 2002). Given the important nexus between financial volatility and output, investment and consumption described above, we estimate the Brexit uncertainty effects on the UK's financial markets' volatilities in section 3.

The potential effects of Brexit are of course not limited to the UK. There is huge potential for spillover, especially to the remaining EU countries, via trade and financial linkages. Yet the impact is uncertain and will depend on the future political and economic relationship between the UK and the EU. According to a majority of analysts other countries are likely to lose out economically. Based on trade linkages (exports to the UK in % of own GDP), Ireland (11.2%), the Netherlands (6.7%) and Belgium (7.5%) are primarily exposed. Regarding banking linkages, the Irish, Dutch, Swedish and German banking sectors are highly

[10] One vision in this respect is the so-called Continental Partnership Proposal delivered by Bruegel (2016), including much free trade and less free movement of labour between the EU and Great Britain. The idea is that free trade substitutes labour mobility.

connected with the British sectors. Based on capital market linkages (FDI and portfolio investment), Ireland, the Netherlands, Luxembourg and France are the most exposed.

The IMF (2016) analyses spillover effects to other (European) countries. Based on financial and trading linkages, Ireland (-0.6 to -2% of GDP), the Netherlands (-0.3% to -0.7% of GDP) and Belgium (-0.25 to -0.65% of GDP) are the most affected countries. Other member states are less affected. Output falls by 0.2 to 0.5% below baseline in the rest of the EU. The European Commission (2016) makes the point that "the referendum has created an extraordinarily uncertain situation". According to its forecasts, the result of the referendum is expected to put pressure on investment and consumption. Therefore, the EC has reduced its GDP growth forecasts for the euro area by 0.1-0.2% for 2016 and 0.2-0.5 for 2017.

Apart from direct economic linkages, Brexit might also generate political and institutional uncertainty about the EU. The UK will be the first country to actually leave the EU under Article 50 which is far from delivering a concrete divorce procedure (Lazowski, 2016). Furthermore, the UK is not the only country where anti-EU movements have gained support. Economic issues, especially the sovereign debt crisis, have facilitated political campaigns especially in France, the Netherlands, and Italy to leave the EU. Also, the success of the Brexit movements might generate momentum for similar movements in other countries increasing the probability of more countries leaving the EU. This might damage the reputation of the EU as a sustainable and irrevocable institution decreasing its political power, influence, and ability to negotiate new supranational contracts like FTA.

Political uncertainty may therefore spread across Europe, especially affecting countries whose sovereign solvency is closely linked to the existence of the EU and the euro area – namely Spain, Portugal, Italy and Greece. Without the euro area or sufficient contributors, rescue mechanisms like the ESM would cease to exist or be perceived as too small to act as a safeguard if member states are in financial difficulties. Furthermore, these countries are still struggling to reach a moderate level of growth and still have trouble in their banking sectors, especially Italy. Existing trade and financial linkages might therefore deliver an incomplete picture about the (relative) magnitude of country-specific spillover effects.[11] Since the Brexit referendum was held very recently, the early assessments of the Brexit vote focused on the financial market effects. Raddant (2016) analyses financial data in the UK, Germany, France, Spain, and Italy. The author performs several standard estimation techniques to compare the behaviour of European stock returns, stock market volatility, and exchange rates before and after the referendum. In contrast to our study, Raddant (2016) focuses more on the immediate impact after the referendum. His study shows that stock markets fell after the referendum (losses ranging between 10-15%) and had similar effects across Europe. In line with our argumentation above, the Italian stock market is mostly affected by the referendum results Brexit (including the UK) despite being the least connected with the UK (in terms of trade and financial linkages). Regarding exchange rate developments, the British pound immediately lost 10% vis-à-vis the USD (8% vis-à-vis the euro). Looking at the response of

[11] Gros (2016), however, puts the assessment of the literature reviewed in section 2 into perspective and states: "(b)eyond a weaker pound and lower UK interest rates, the referendum has not had much of a lasting impact. Financial markets wobbled for a few weeks after the referendum, but have since recovered. Consumer spending remains unmoved". While it is true that consumer spending stayed rather constant, we note in this section that business and consumer confidence went down. See also our remarks in section 4.

the sterling exchange to poll results in advance of the referendum numbers shows that investors appear to view Brexit as a negative event (Arnorsson and Zoega, 2016).

The second relevant study for our research is the short paper by Krause et al. (2016), which argues that the referendum in the UK created a high degree of uncertainty about possible consequences and that this could also be seen in financial markets in the run-up to the referendum. According to their empirical investigation, poll results pointing towards Brexit resulted in short-term declines in returns of bank indices. According to the authors, this suggests that negative consequences of exiting the EU are expected not only for the UK but also for the EU. Their results point to a strong depreciation of UK sterling relative to the euro or the Swiss franc, which might reflect the (expected) decline in the attractiveness of the UK as a financial centre and reduced demand for the UK sterling.

The results of Krause et al. cannot be compared in quantitative terms with ours due to differences in the variables measuring the probability of Brexit. They employed a pure dummy variable using poll results from 'whatukthinks.org' amounting to 0 if the probability fell below 50% and is equal to 1 if the probability was higher than 50%. In our view, this risks being too crude a measure, which does not adequately measure the likelihood of a Brexit vote and therefore its potential adverse effects. A general critique against measuring the effects of a Brexit vote using poll results is presented by Gerlach (2016). He argues that poll data contribute little to the explanation of financial market developments. We therefore utilise more sophisticated measures by using the probability of a Brexit vote based on data from betting agencies.

The third, again less comprehensive, study comparable to ours is Gerlach and Di Giamberardino (2016). They projected that the outcome of the UK's referendum on EU membership could have a significant effect on sterling. They estimate the potential size of this effect by looking at the relationship between daily changes in the sterling exchange rate and bookmakers' odds of Brexit. According to their estimations, movements of between 5% and 15% seem plausible. We use an almost identical approach, but do not restrict our estimations on the effects on exchange rates.

2. Brexit and its effect on UK financial market volatilities

2.1 Data

In this section, we estimate the magnitude and the sign of short-run Brexit effects that are related to an environment of increased policy uncertainty during the time before the referendum and directly after Brexit-vote on UK financial markets. Our focus here is on volatilities (second statistical moments) rather than changes of levels (first statistical moment).

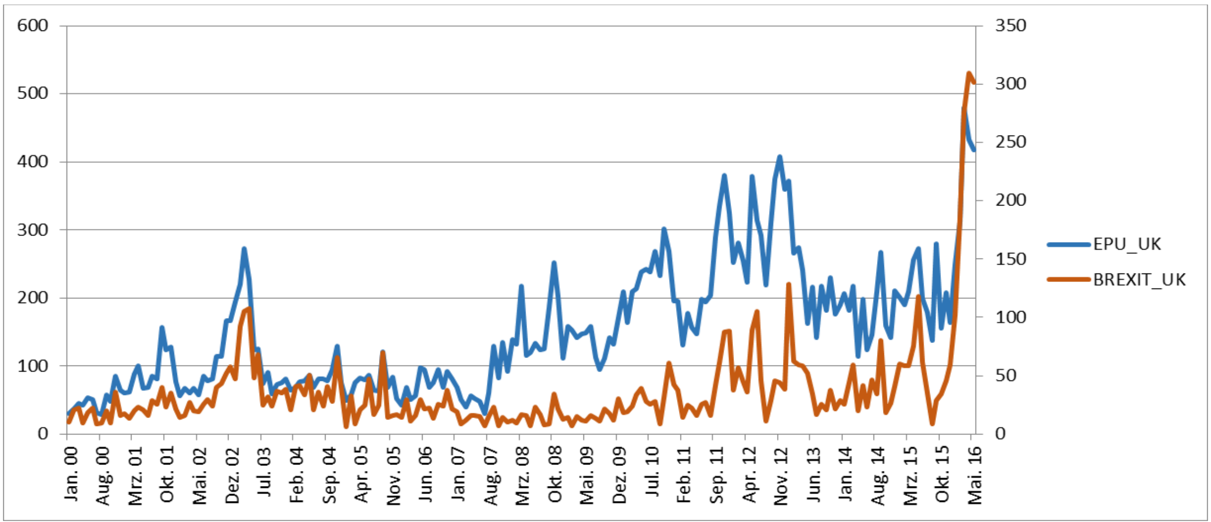
As a measure of uncertainty, we employ the Economic Policy Uncertainty index (EPU) developed by Scott R. Baker, Nicholas Bloom and Steven J. Davis,[12] which draws on newspapers and other written sources and is calculated as scaled counts of articles containing 'uncertain' or 'uncertainty', 'economic' or 'economy', and one or more policy-relevant terms ('tax', 'policy', 'regulation', 'spending', 'deficit', 'budget', or 'central bank'). Policy-driven uncertainty is shown to increase during political turmoil or elections, as well as

[12] See http://www.policyuncertainty.com/index.html.

during the implementation of major policies and programmes and reflects the level of doubt and confusion in the private sector caused by government policies. According to its definition, using the EPU Index should thus be a good proxy for the estimations of Brexit uncertainty and Brexit-vote effects. The other index provided by the same source - the Brexit Uncertainty index – is calculated by multiplying the EPU index by the share of EPU articles that contain 'Brexit', 'EU' or 'European Union'. It is available only until May 2016.

Figure 2 shows that the EPU index in the UK close to the referendum hovered at its highest point, exceeding previous records during the Scottish referendum, the eurozone crisis, the Gulf war and the global financial crisis of 2008. Further visual inspection of the EPU and Brexit uncertainty reveals a strong, although time-varying, correlation of both during the period before the referendum.

Figure 2. UK economic policy uncertainty (EPU) and Brexit uncertainty before the referendum



Source: (http://www.policyuncertainty.com/).

In our empirical estimations, we will use EPU instead of Brexit uncertainty, for two reasons. First, EPU index is highly correlated with the Brexit uncertainty index during the time before the referendum. In contrast to the Brexit uncertainty index, Economic Policy Uncertainty data is also available for the post-referendum period, and thus allows us to estimate the effects of uncertainty triggered by the Brexit vote. In this context, it is important to note that the current lack of impact can be explained by the fact that Brexit has not yet happened (Begg, 2016).

Second, since financial markets are very flexible and able to react to news immediately, using daily EPU data could be beneficial compared to Brexit uncertainty data, which is only available monthly.

Our model includes the following variables:

- Daily stock market volatility[13] calculated as the annualised daily percent standard deviation of daily high and low FTSE 250 prices:

$$FTSE250v_t = 100\sqrt{365 \times 0.361 \times \left[ln\left(FTSE250_t^{high}\right) - ln\left(FTSE250_t^{low}\right)\right]^2}$$

[13] For more details on the construction of daily volatilities, refer to Alizadeh et al. (2002).

We have decided to consider FTSE 250 prices instead of FTSE 100 since the first might be a better gauge of domestically oriented share prices than the FTSE 100, which is dominated by multinationals, some of which have little exposure to the UK economy (Sheffield, 2016).

- Daily UK pound sterling volatility calculated as the annualised daily percent standard deviation of intraday high and low exchange rate GBP/USD:

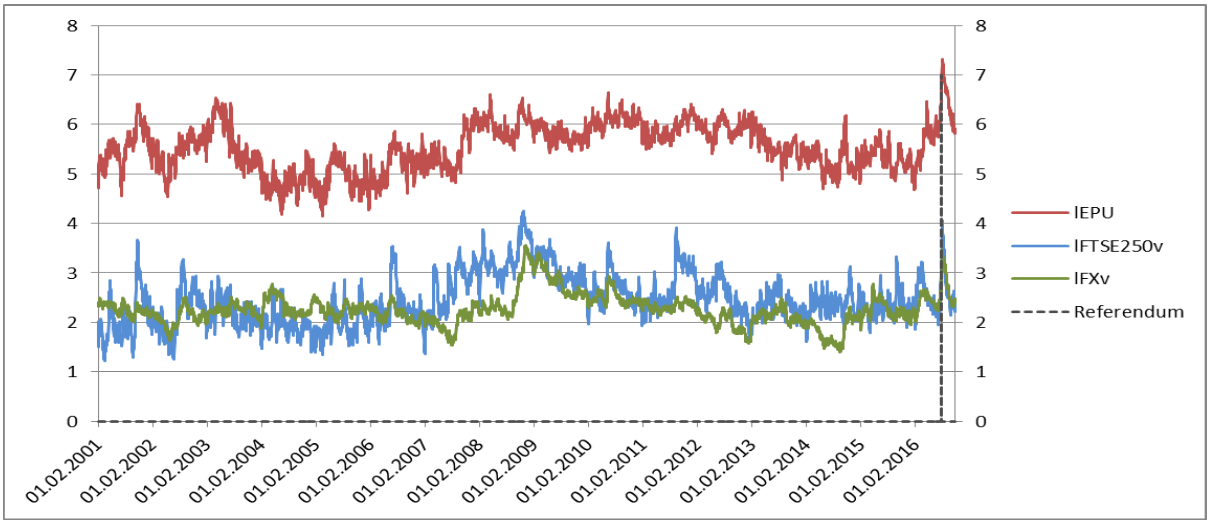
$$FXv_t = 100\sqrt{365 \times 0.361 \times \left[ln\left(FX_t^{high}\right) - ln\left(FX_t^{low}\right)\right]^2}$$

- Daily EPU index[14] constructed by Baker et al. (2015)

Additionally, in order to disentangle domestic policy uncertainty from global uncertainty, we have included the CBOE Volatility Index (VIX Index)[15] as an exogenous variable.

The sample contains 4105 observations, from 2001:01:01 to 2016:23:09, all variables are taken in logs and plotted in Figure 3, below.

Figure 3. Financial volatilities and EPU index, logs



Sources: Own formulation.

In Figure 3, we observe that both stock prices and exchange rates went through a major period of volatility during the global financial crisis. Stock prices also experienced increased volatility around August 2011, which could be explained by the effects of the euro crisis (Gros, 2011). Moreover, there is a considerable upward spike at the time of the referendum (23 June 2016, marked as a vertical line) for all variables under consideration as magnitudes reach levels comparable to previous maxima.

[14] In cases where the index was equal to 0, we have replaced it with the value from the previous day.

[15] Empirical realisations of the VIX index, intraday high and low values of FTSE250 and the GBP/USD exchange rates are obtained from the Datastream database.

2.2 Estimation approach

In order to estimate the effect of policy uncertainty on volatility in financial markets, we will use the empirical approach proposed by Diebold and Yilmaz (2009, 2012) based on VAR variance decompositions.[16]

Firstly, we estimate the VAR(p) model:

$$x_t = \sum_{i=1}^{p} \Phi_i x_{t-i} + \varepsilon_t \quad , \tag{1}$$

where $\varepsilon \in (0, \Sigma)$ is the i.i.d. errors vector.

The moving average representation, thus, could be written as

$$x_t = \sum_{i=0}^{\infty} A_i \varepsilon_{t-i}, \tag{2}$$

where $A_i = \sum_{k=1}^{p} \Phi_k A_{i-k}$, A_0 is the identity matrix $I_{N\times N}$ and $A_i = 0$ for $i < 0$.

Our further analysis relies on variance decompositions, which allows us to assess the fraction of the H-step-ahead error variance in forecasting x_i that is due to shocks to x_j. In order to deal with contemporaneous correlations of VAR shocks, we use the generalised VAR framework, which produces variance decompositions that are invariant to choice of ordering. The generalised approach allows correlated shocks, taking into account the historically observed distribution of errors.

The H-step-ahead forecast error variance decomposition is calculated as

$$\theta_{ij}^{g}(H) = \frac{\sigma_{ii}^{-1} \sum_{h=0}^{H-1} (e_i' A_h e_j)^2}{\sum_{h=0}^{H-1} (e_i' A_h \Sigma A_h e_i)}, \tag{3}$$

where Σ is the variance matrix for the errors ε, σ_{ii} is the standard deviation of the error term for the i-th equation of VAR and e_i is a vector that contains one as i-th element and zeros otherwise.

The *total volatility spillover index* is then constructed as:

$$S^{g}(H) = \frac{\sum_{\substack{i,j=1 \\ i\neq j}}^{N} \widetilde{\theta_{ij}^{g}}(H)}{\sum_{i,j=1}^{N} \widetilde{\theta_{ij}^{g}}(H)} \times 100, \tag{4}$$

where $\widetilde{\theta_{ij}^{g}}(H)$ is normalised value for $\theta_{ij}^{g}(H)$, so that $\widetilde{\theta_{ij}^{g}}(H) = \frac{\theta_{ij}^{g}(H)}{\sum_{j=1}^{N} \theta_{ij}^{g}(H)}$. The total spillover index, thus, measures the contribution of spillovers of shocks across variables under consideration to the total forecast error variance.

[16] Alternatively, Hafner and Herwartz (2006b) proposed a concept of impulse response functions tracing the effects of independent shocks on volatility and then considered the effect of historical shocks, such as 'Black Wednesday' and an announcement by EC finance ministers on 2 August 1993, on the foreign exchange market. However, we believe that the identification of a 'Brexit shock' is not trivial and should not be restricted to the day of the announcement of the referendum results, but should include the days preceding the referendum. Moreover, the applied approach in this paper allows us to take into account the time-varying volatility of multivariate financial time series.

In order to investigate the direction of spillovers across financial volatilities and policy uncertainty, i.e. the portion of total spillover index that comes from x_i to all other variables, *the directional spillover* is applied:

$$S_i^g(H) = \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N} \widetilde{\theta_{ji}^g}(H)}{\sum_{j=1}^{N} \widetilde{\theta_{ji}^g}(H)} \times 100 \tag{5}$$

The net spillover from variable *i* to all other variables *j* is obtained as the difference between gross shocks transmitted to and gross shocks received from all other markets:

$$S_i^g(H) = \left(\frac{\sum_{\substack{j=1 \\ j\neq i}}^{N} \widetilde{\theta_{ji}^g}(H)}{\sum_{j=1}^{N} \widetilde{\theta_{ji}^g}(H)} - \frac{\sum_{\substack{j=1 \\ j\neq i}}^{N} \widetilde{\theta_{ij}^g}(H)}{\sum_{j=1}^{N} \widetilde{\theta_{ij}^g}(H)} \right) \times 100 \tag{6}$$

The last spillover measure of interest is *the net pairwise spillover* index between variables x_i and x_j which is defined as the difference between gross shocks transmitted from x_i to x_j and gross shocks transmitted from x_j to x_i:

$$S_i^g(H) = \left(\frac{\widetilde{\theta_{ij}^g}(H)}{\sum_{k=1}^{N} \widetilde{\theta_{ik}^g}(H)} - \frac{\widetilde{\theta_{ji}^g}(H)}{\sum_{k=1}^{N} \widetilde{\theta_{jk}^g}(H)} \right) \times 100 \tag{7}$$

The chosen approach allows us to investigate the dynamics of spillovers in the form of rolling regressions, and thus the time variations of total, directional, net and net-pairwise spillovers in the periods before and after the Brexit referendum, which are of particular interest to this study.

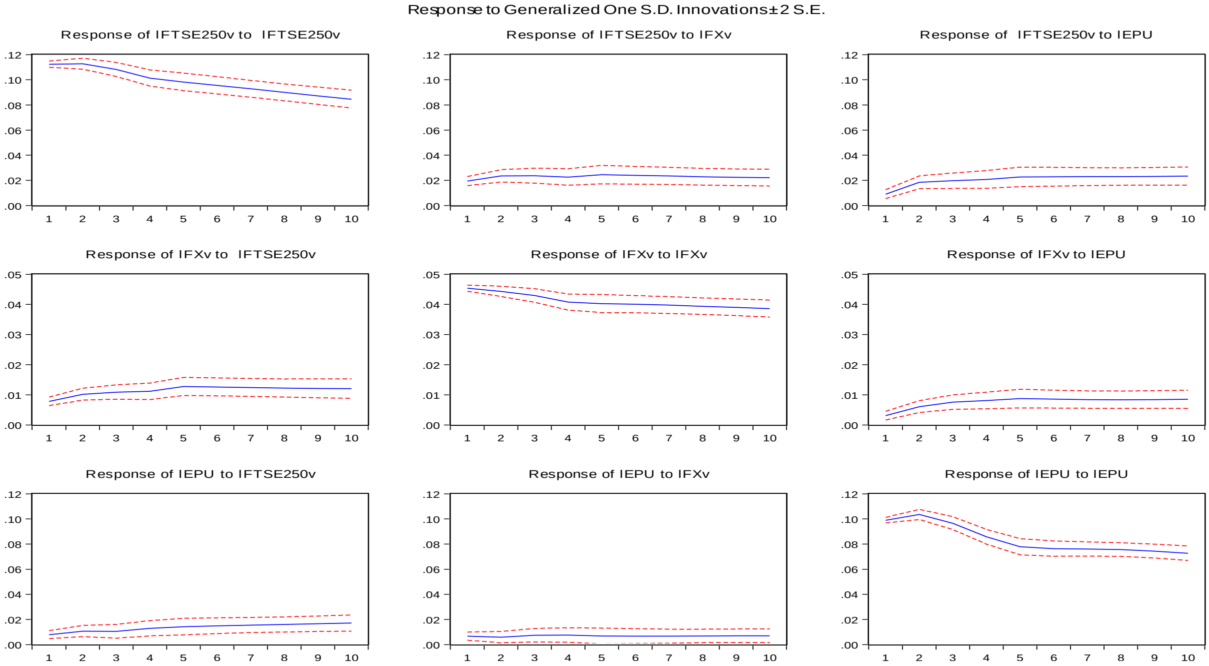
The lag length of five was chosen according to the Akaike Information Criterion, the residuals are not serially correlated, according to the unit root test the model could be considered as dynamically stable.[17]

The generalised impulse responses are significant and display the expected signs.[18]

[17] Our VAR model specification tests are presented in Table A1 in the Appendix.

[18] Different Cholesky orderings do not change the signs or the significance of the impulse responses. The results are available upon request.

Figure 4. Generalised impulse responses functions, full-sample estimations



According to the Granger causality test, whose results are presented in Table 1a, policy uncertainty indeed 'Granger-causes' stock and exchange rate volatilities. Apart from the standard Granger causality approach in the recent empirical literature, a number of new causality-in-variance tests have been developed, for instance, a Portmanteau test of Cheung and Ng (1996), a Lagrange Multiplier Test of Hafner and Herwartz (2006a) and a Wald test of Hafner and Herwartz (2008). Based on Monte Carlo investigations, the latter two methodologies are shown to be preferable for applied work (Hafner and Herwartz 2006a, 2008). In this study, we perform a causality test based on Quasi Maximum-Likelihood methods proposed by Hafner and Herwartz (2008). The approach relies on multivariate GARCH estimations and consequent Wald testing of appropriate coefficients' set. Our test results (see Table 1b) indicate some evidence of bi-directional causality between policy uncertainty and financial volatilities, which means that not only policy uncertainty affects financial markets, but also exaggerated financial volatility adds to uncertainty about policy measures to support the economy and thereby mitigate downside risks.

Table 1. Causality tests

a) VAR Granger Causality/Block Exogeneity Wald Tests

Dependent variable: lFTSE250v				Dependent variable: lFXv				Dependent variable: lEPU			
Excluded	*Chi-sq*	*df*	*Prob*	*Excluded*	*Chi-sq*	*df*	*Prob*	*Excluded*	*Chi-sq*	*df*	*Prob*
lFXv	8.04	5	0.15	lFTSE250v	19.43	5	0.00	lFTSE250v	16.57	5	0.01
lEPU	37.31	5	0.00	lEPU	22.66	5	0.00	lFXv	3.13	5	0.68
All	*47.91*	*10*	*0.00*	*All*	*48.33*	*10*	*0.00*	*All*	*20.28*	*10*	*0.03*

b) Variance causality test based on Hafner and Herwartz (2008)

MV-GARCH, BEKK - Estimation by BFGS
1) Test for causality of EPU to FTSE250, FX Chi-Squared(4)=46.35 or F(4,*)=11.59 with Significance Level 0.000
2) Test for causality of FTSE250, FX to EPU Chi-Squared(4)=86.39 or F(4,*)=21.60 with Significance Level 0.000

For the rolling estimations, we have set a rolling window of 500 working days and a forecast horizon of 10 working days.[19]

2.3 Estimation results

We start with the analysis of our results in Table 2, which provides an input–output decomposition of the total spillover index based on full-sample estimations. According to the table, policy uncertainty shocks contributed 4.1% (3rd column, first row) and 3.2% (3rd column, second row) to the variance decompositions of stock market and exchange rate volatilities respectively. Policy uncertainty was mostly affected by stock volatilities (2.63 %), whereas the FX market's contribution to the policy uncertainty forecast error variance is minor (0.64%). The total spillover index for all variables is thus equal to 7.5 %. However, this value should be taken with caution, since the estimation was performed employing data for the full sample. Thus, the spillover index is only the average measure of spillovers in the period from January 2001 to September 2016. In order to assess the extent and nature of the *spillovers variation over time*, we continue with the rolling estimations.

Table 2. Full-sample spillover table

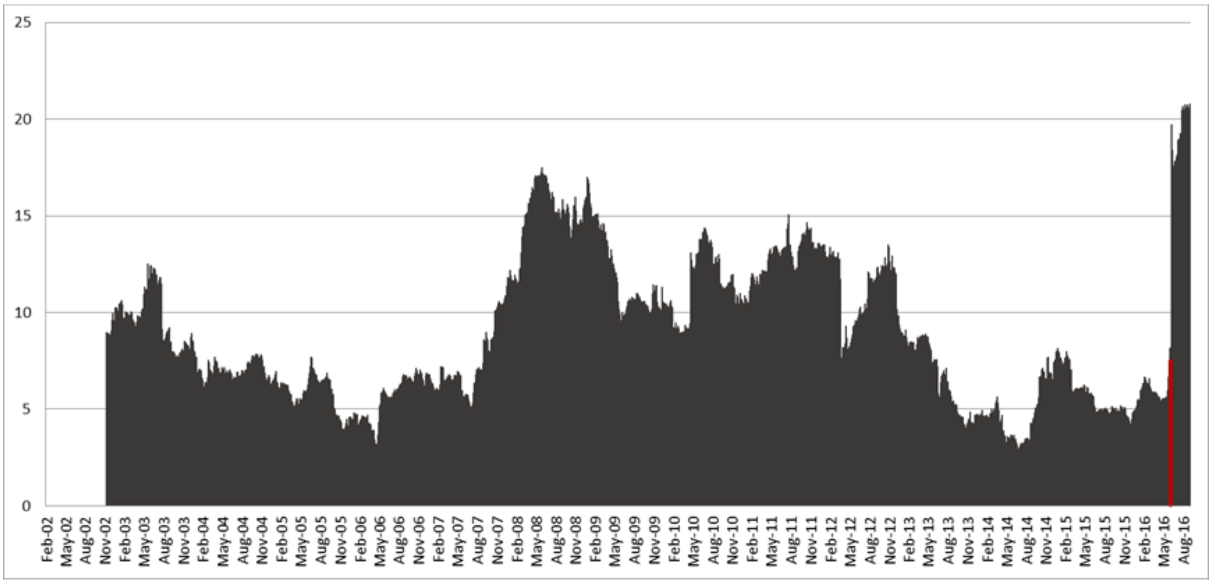
	lFTSE250v	*lFXv*	*lEPU*	*From Others:*
lFTSE250v	91.02	4.88	4.1	*9*
lFXv	7.03	89.77	3.2	*10.2*
lEPU	2.63	0.64	96.73	*3.3*
Contribution to others:	*9.7*	*5.5*	*7.3*	*22.5*
Contribution including own:	*100.7*	*95.3*	*104*	*7.50%*

Note: The *ij*-th element of the table represents the estimated contribution to the forecast error variance of x_i coming from innovations to x_j.

Our rolling estimations for total spillovers between stock volatility, FX volatility and policy uncertainty (see Figure 5) show an increase in spillovers during the period from the end of 2008 till the end of 2012, which could be attributed to the subprime-mortgage crisis, the global financial crisis, and the sovereign debt crisis. The consequent huge rise of the spillover index directly after the Brexit referendum has exceeded all historical maxima.

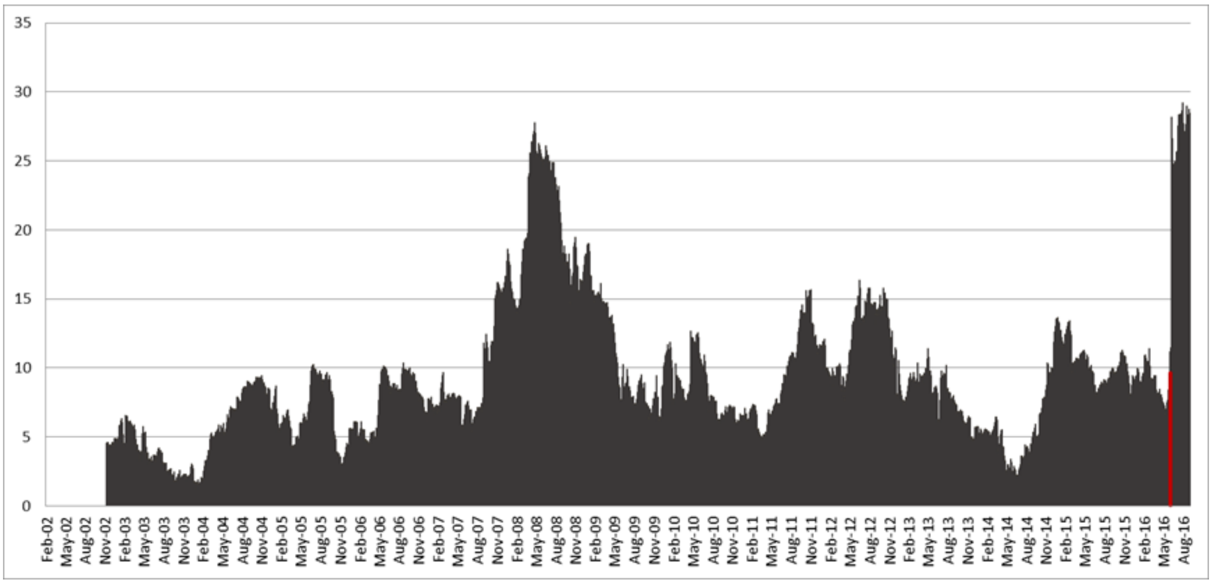
[19] As a robustness check we performed estimations with different lag length, rolling windows and forecast horizons - the basic results remain, see Figure A1 in the Appendix.

Figure 5. Total Spillover Index



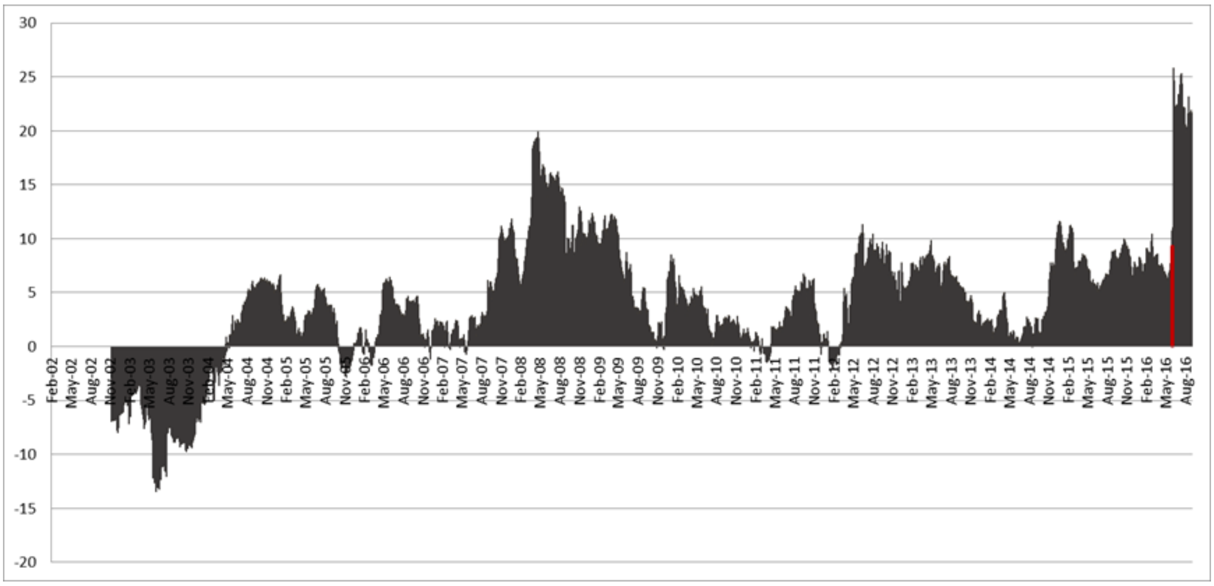
In Figure 6, we observe that the spike of total spillover index at the end of our sample is indeed due to increased spillovers *from policy uncertainty to financial market volatilities*.

Figure 6. Directional spillovers from EPU to financial volatilities



According to our results in Figure 7, starting in May 2004, the index of net spillovers from EPU to financial volatilities has a positive value apart from some minor exceptions. This means that since 2004 policy uncertainty has been a net shock contributor to financial market volatilities, or in other words, policy uncertainty shocks have influenced financial markets to a larger extent than financial market volatility shocks. However, the value of the net spillover index changed dramatically after the Brexit-vote and increased from 9% to 26%, remaining dominant until the end of our sample.

Figure 7. Net spillovers from EPU to financial volatilities



Our final empirical exercise in this section looks at the pairwise net spillovers (Figures 8 to 10) in order to reveal bilateral relationships between the variables under consideration. According to Figure 8, stock price volatility was a net receiver of policy uncertainty shocks as from February 2016 – the month when the Brexit referendum was announced.

Figure 9 provides the net spillovers between exchange rate volatility and EPU. Starting in May 2006, policy uncertainty shocks dominate in net terms, with some exceptions. Like the net spillovers between stock volatility and EPU, the Brexit referendum resulted in an increase in net spillovers between FX volatility and policy uncertainty.

From the net spillovers between stock and FX volatilities presented in Figure 10, we observe that the FX market was a net recipient of large levels of stock volatility shocks, starting in 2007 up to the end of 2013, and afterwards became a net transmitter to the stock market. The time right before and after the Brexit vote does not exhibit any extraordinary patterns in the relationship between financial volatilities.

Figure 8. Net pairwise spillovers between stock volatility and EPU

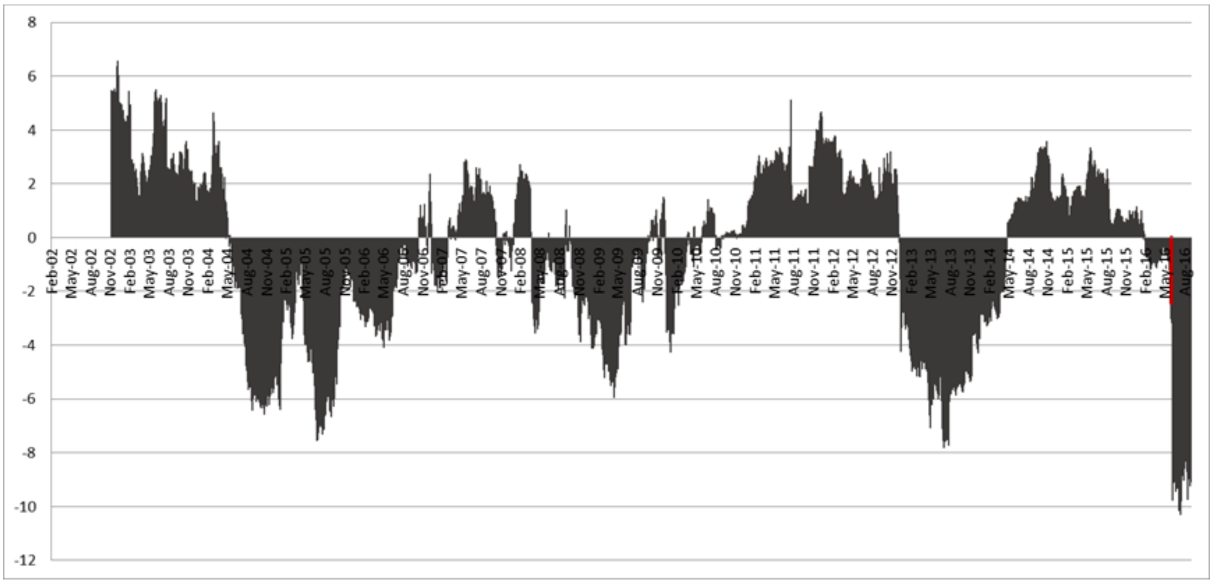


Figure 9. Net pairwise spillovers between FX volatility and EPU

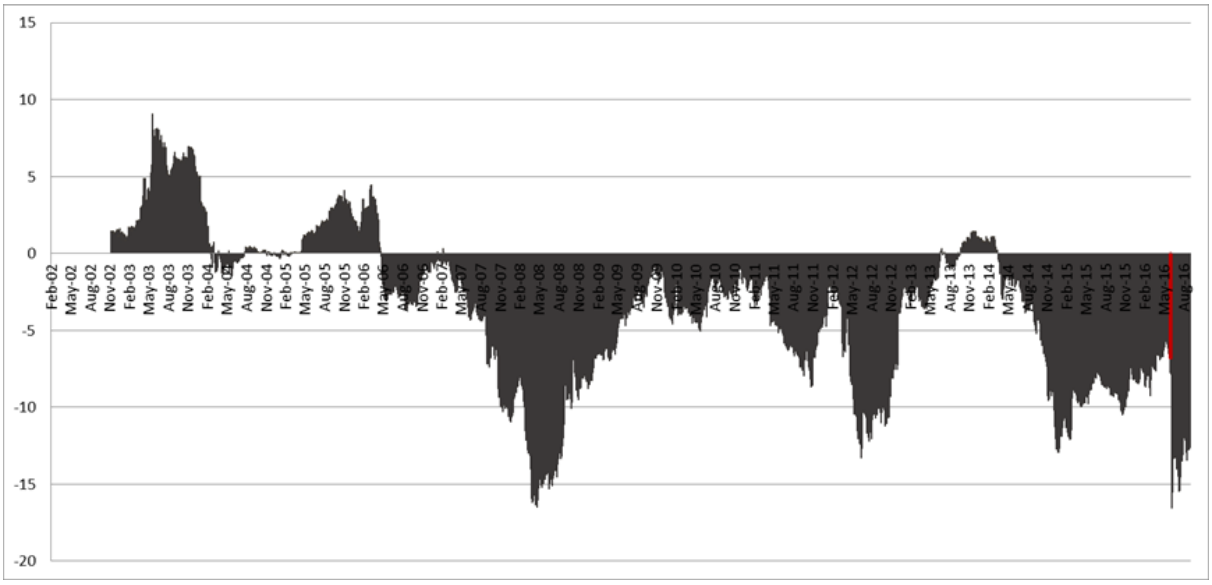
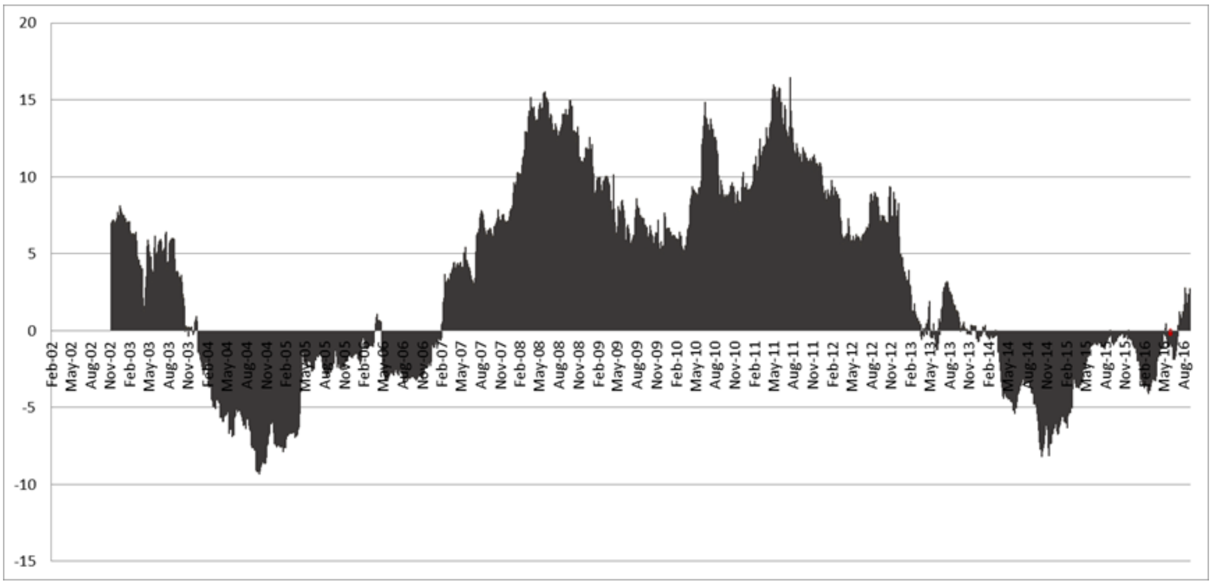


Figure 10. Net pairwise spillovers between stock volatility and FX volatility



To conclude this section, our estimation reveals the substantial role of policy uncertainty on financial market volatilities. Policy uncertainty after 23 June 2016 induced huge spillovers to financial markets, which exceeded all previous historical maxima. Interestingly, policy uncertainty spillovers have remained strong since then and could be considered as empirical evidence that policy uncertainty about the development of the relationship between the UK and the EU causes turbulence in financial markets, even three months after the referendum, which could further weaken investment and hiring in the UK (and Europe). Overall, we can corroborate the view of IMF (2016) and others that Brexit uncertainty has caused instability in key financial markets. Our analysis also provides evidence that the observed immediate effect has not decreased or even disappeared but remains steadily high, and thus might prevail also over the medium run.

3. Brexit and its effects on international financial markets

3.1 Data

In this section, we analyse the effect of Brexit on international financial markets. In this context, we estimate the impact of the increase in the likelihood that the citizens of the UK would vote for Brexit on several financial variables. We use daily data between the 1 April and 23 June 2016, thereby examining the critical phase before the EU referendum took place. We include data from the following countries: Austria, Belgium, Canada, Denmark, Finland, France, Germany, Netherlands, Norway, Italy, Japan, Portugal, Spain, Sweden, Switzerland, the UK and the US.

Table 3. National stock indices

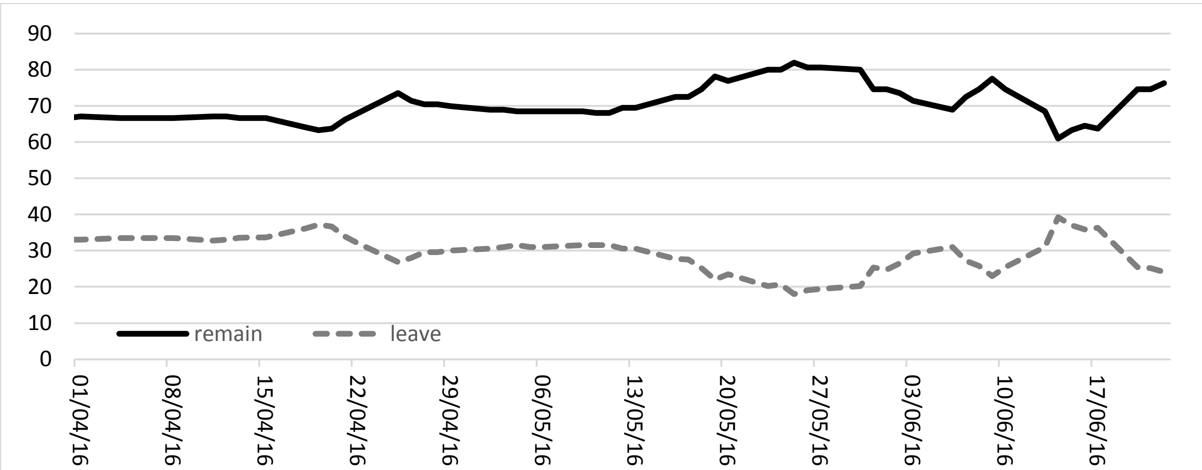
Country	Stock index	Country	Stock index
Austria	ATX	Ireland	ISEQ20
Belgium	Bel20	Italy	FTSE MIB
Canada	S&P/TSX Composite	Japan	Nikkei 225

Denmark	OMX Copenhagen 20	Portugal	PSI-20
Finland	OMX Helsinki 25	Spain	IBEX 35
France	CAC 40	Sweden	OMX Stockholm 30
Germany	DAX	Switzerland	SMI
Greece	ASE	United Kingdom	FTSE 100
Netherlands	AEX	United States	S&P 500
Norway	OBX		

Our measures of daily stock returns are based on the closing prices of the most important stock indexes of the countries under observation (see Table 3). Furthermore, we analyse the impact on 10-year government yields and sovereign CDS for 10-year bonds that measure sovereign credit risk. In order to examine the impact of the increase in the probability of Brexit on the external value of the British currency, we use the exchange rate of the British pound vis-à-vis the Canadian dollar, Danish krone, euro, Japanese yen, Norwegian krone, Swedish krona, Swiss franc and the US dollar. When not stated otherwise, the data is obtained from Thomson Reuters Datastream.

The most crucial variables of this study are the variables that tracked the probability of a Brexit vote. We use two different measures to check the robustness of our results. Firstly, we use probability data in percentage points (*Brexit_Prob*) based on decimal odds of the online betting exchange 'Betfair.' As probabilities vary intra-daily, we have to make a choice regarding the time of day. We use the 4pm (GMT) values. As financial markets are considered to be very fast in processing new information, we assume that new information arriving at 4pm (GMT) should be fully reflected in the daily closing prices.[20] Secondly, we attempt to measure the probability of a Brexit vote by using survey (poll) data collected by Bloomberg (*Brexit_Poll*).[21] Our variables to track the probability of Brexit are presented in Figures 11 and 12.

Figure 11. Probability of Brexit before the referendum (in percentage points)



[20] Additionally, we performed several estimations using 12pm (GMT) values and obtained almost identical results.

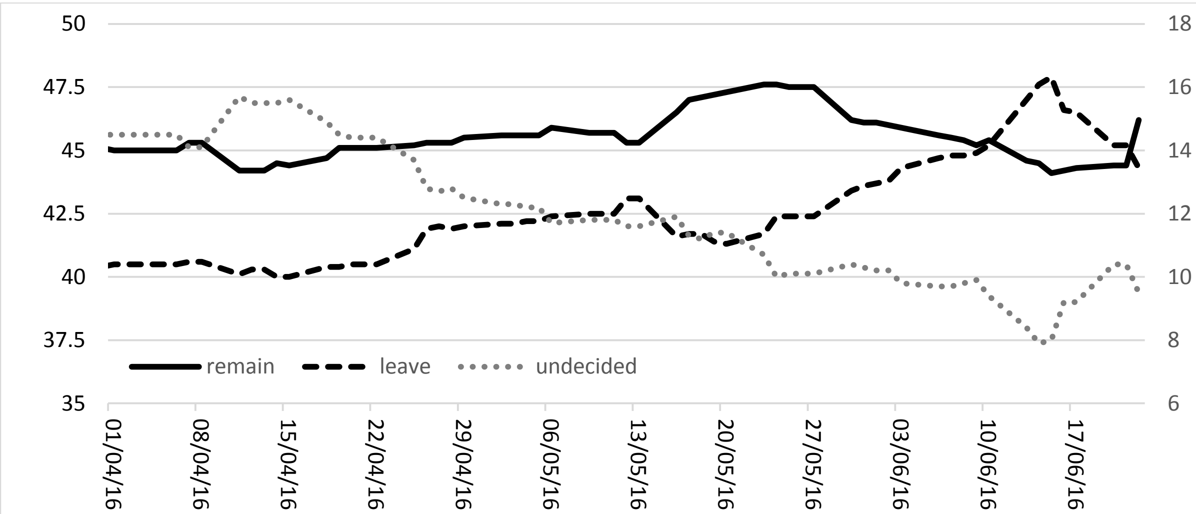
[21] Further information can be found here: http://www.bloomberg.com/graphics/2016-brexit-watch/

Source: Betfair.

Both figures show a similar evolution about the implied chance of a Brexit vote. In both cases, we can observe a sideways movement until mid-May, followed by a noticeable strengthening of the 'remain' campaign. However, starting around the end of May, the 'leave' campaign gains momentum until mid-June. Although the probability of a Brexit vote does not reach 50%, the leave campaign overtook the remain side in polls in mid-June. Close to the referendum, we see another strong increase for the remain campaign in both variables.

Although we include both Brexit variables alternatively in our estimations, we focus our analysis mainly on *Brexit_Prob*. As shown by Gerlach (2016), the information content of polls and survey data for explaining developments of financial variables is generally low. We can confirm this argument because the explanatory power of *Brexit_Poll* is low in general, as indicated by the R^2 in our estimations.

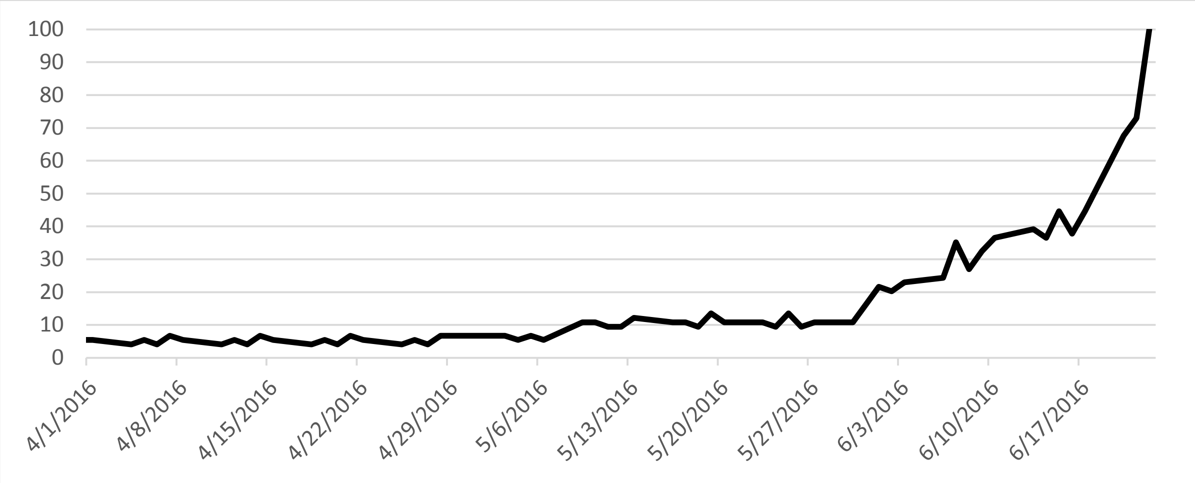
Figure 12. Summary of Brexit polls



Source: Bloomberg.

While it can be assumed that changes in the probability of a Brexit vote should have had an impact on fast information-processing markets, it is safe to assume that timing also matters. An increase in the probability three months before the date of the referendum might have had a smaller effect compared to a similar increase one day before the vote. Similarly, one may assume that during times of high public attention the effects on financial markets might be stronger. Both aspects are highly interconnected because public interest should be at its highest point just before the vote takes place.

Figure 13. Public attention based on Google search requests



Source: Google Trends.

In order to account for these aspects, we use Google Trends data to check for the public interest in Brexit based on Google search requests.[22] The values displayed in Figure 13 present a measure of 'public attention' for Brexit in the entire United Kingdom and are ratios compared to the day with the highest attention within the time period under observation.

3.2 Estimation procedures

In order to analyse the impact of the Brexit referendum, we use standard econometric procedures. As the first step of our analysis, panel estimation is used to obtain first results. As common in the literature, our choice of the specific panel estimator depends on the results of the Hausman-test. In our study, the null hypothesis of the test is accepted for every specification. Therefore, we exclusively use the *random effects* estimator. Subsequently, we perform SUR estimations to obtain country-specific results. The SUR approach consists of several regression equations that are linked by allowing for cross-equation correlations of the error terms. This appears to be an appropriate assumption because financial markets are highly interconnected. Although every country-specific equation can be consistently estimated by GLS, the use of SUR estimation increases the efficiency of the estimations. Additionally, in order to account for the timing of the change in Brexit-vote probability, we estimate specifications in which the observations points are weighed based on Google Trends data.

Table 4. Overview of variables used in estimation

Variable	**Description**	**Variable**	**Description**
$Brexit\_Prob_t$	The change in the Brexit probability in t	CDS_t^i	The percentage change in the CDS in t of country i
$Brexit\_Poll_t$	The change in the support	$Comm_t$	The percent change in commodity

[22] The values are based on the search topic: "United Kingdom European Union membership referendum, 2016" which combines several different research requests corresponding with the Brexit topic. The following additional options are used: Search Category: "News", Search: "News-Search".

	for the leave campaign in t		prices in t
$stock_t^i$	The percent change in stock prices in t in country i	ExR_t^i	The percent change in the British pound against the national currency of country i in t
$IR10_t^i$	The change in the 10-year interest yield in t for country i	$diff\_IR10_t^i$	The change in the long-term interest rate differential ($IR10_t^i - IR10_t^{UK}$) in t.
$Future3x6_t^i$	The change in the 3-month future for the 3-month interest rate in t in country (currency area) i	$diff\_IR10_t^i$	The change in the 3-month future of the 3-month interest rate differential ($Future3x6_t^i - IFuture3x6_t^{UK}$) in t.

We include several control variables that are likely to affect financial variables. First, we control for changing expectations regarding monetary policy by including three-month futures of the three-month interest rate ($Futures3x6_t^i$). For similar reasons, we include the national long-term interest yield ($IR10_t^i$) as explanatory variable in several specifications. Second, we use the S&P commodity price index ($COMM_t$) which is supposed to be an indicator of changing expectation about the performance of the global economy. Table 4 presents an overview of our variables.

3.3 Estimation results

3.3.1 Impact on international stock returns

Our first objective is to analyse the effect of Brexit-vote probability on international stock markets. In our opinion, the effect on stock markets can be assumed to be universally negative. However, there might be differences regarding the magnitude based on the strength of trade and financial linkages between the UK and the economy under observation.

In accordance with the assumption that financial markets, and especially stock markets are (information) efficient, we do not include lagged values of the Brexit variables. Because all new information is supposed to be included in prices on arrival, information that has already been available on previous days should have no effect on present-day stock market returns.[23]

The dividend discount model assumes that stock prices are not only influenced by the expected level of dividends (and therefore by the expectation of general economic development) but also by current and future (short-term) interest rates (see section 1). According to announcements by the Bank of England and to a lesser extent the European Central Bank, it could be expected that central banks would react in their attempt to counterbalance potential adverse effects.[24] Therefore, the effect of the likelihood of a Brexit vote on stock markets might be underestimated if a variable measuring expectations about future monetary policy is not included in the model.

[23] We performed several estimation with lags of the variables. In the vast majority of cases, the lagged variable turned out to be insignificant. The same argument also applies to the other estimations in this section.

[24] In August 2016, the BoE decreased the bank rate to 0.25% justifying their decision by potential effects of the Brexit vote on future inflation and growth.

Table 5. Effect of Brexit-vote likelihood on stock markets ($stock_t^i$); panel estimation

	Random Effects							
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
$Brexit\_Prob_t$	-0.1372 (0.000)	-0.1421 (0.000)	-0.1373 (0.000)	-0.1258 (0.000)				
$Brexit\_Poll_t$					-0.4243 (0.000)	-0.4385 (0.000)	-0.4163 (0.000)	-0.4052 (0.000)
$Future3x6_t^i$		-0.0207 (0.1284)				-0.0227 (0.2132)		
$IR10_t^i$			-0.0555 (0.000)				-0.5564 (0.000)	
$Comm_t$				0.2691 (0.000)				0.2780 (0.000)
Pseudo R^2	0.0791	0.0818	0.1348	0.1712	0.0209	0.0219	0.0788	0.1214
Hausman p-value		0.4123	0.9100			0.2876	0.8333	

Note: Constants are included. p-values are presented in brackets. The Newey-West estimator is used for the calculation of the covariance matrix. Individual and time effects are included. Estimation period: 01.04.16 – 23.06.16.

Our estimation results are presented in Tables 5 and 6. The estimated coefficients of the Brexit variables presented in both tables measure the effects of a one-percentage point increase in the probability of Brexit ($Brexit\_Prob$) or Brexit polls ($Brexit\_Poll$) on stock prices, in percent. Our panel estimations reveal strong evidence that an increase in the likelihood of a Brexit vote (based on both variables) has a strong negative effect on stock prices. For $Brexit\_Prob$, we find a decrease in stock prices of around 0.13%. A one-percentage point increase in $Brexit\_Poll$ leads to a decrease of around 0.42%. Both results appear to be robust to the inclusion of commodity prices as well as indicators of future monetary policy.

The SUR estimation results confirm the panel results but shed light on country differences. While the largest effects are found for UK stocks when measured in USD, the effects on US and Canadian stock prices turn out to be weaker than the effects on European economies. For both economies, the results become insignificant when we include additional control variables such as $COMM_t$. Regarding differences between European countries, the effects are similar overall. It is therefore somewhat difficult to trace back the results to the strength of trade, banking or capital market linkages. However, we observe a tendency that the effects for the GIIPS[25] states is stronger, with the exception of Greece. Based on the amount of economic ties between the UK and Ireland, it comes as no surprise that Irish stock prices are strongly affected due to economic ties. For Italy, Spain and Portugal the strong effect is surprising and cannot be solely explained by the strength of economic ties with the UK. When we weight the observation by Google Trends data, the effects are stronger and significant for all countries, indicating that timing does in fact matter.

[25] The GIIPS states comprise Greece, Ireland, Italy, Portugal and Spain.

Table 6. Effect of Brexit-vote likelihood on stock markets $stock_t^i$; SUR Estimation

	(1)	(2)[26]	(3)	(4)	(5)	(6)
Exo. Variables	$Brexit\_Prob_t$	$Brexit\_Prob_t$ $Future3x6_t^i$	$Brexit\_Prob_t$ $IR10_t^i$	$Brexit\_Prob_t$ $Comm_t$	$rexit\_Prob_t$ (weighted estimation)	$Brexit\_Poll_t$
Austria	-0.1500 (0.004)	-0.1426 (0.012)	-0.1494 (0.005)	-0.1337 (0.001)	-0.2268 (0.000)	-0.5023 (0.062)
Belgiun	-0.1503 (0.003)	-0.1473 (0.005)	-0.1524 (0.001)	-0.1395 (0.001)	-0.2292 (0.000)	-0.3684 (0.209)
Canada	-0.0452 (0.067)	-0.0452 (0.066)	-0.0316 (0.205)	-0.0318 (0.053)	-0.0690 (0.000)	-0.2503 (0.003)
Denmark	-0.1709 (0.001)	-0.1492 (0.000)	-0.1627 (0.001)	-0.1624 (0.001)	-0.2269 (0.000)	-0.3508 (0.005)
Finland	-0.0968 (0.182)	-0.0943 (0.203)	-0.1025 (0.150)	-0.0797 (0.193)	-0.2245 (0.000)	-0.4785 (0.000)
France	-0.1818 (0.002)	-0.1771 (0.002)	-0.1823 (0.001)	-0.1689 (0.000)	-0.2750 (0.000)	-0.4979 (0.063)
Germany	-0.1586 (0.006)	-0.1543 (0.008)	-0.1559 (0.008)	-0.1449 (0.002)	-0.2545 (0.000)	-0.5272 (0.040)
Greece	-0.1223 (0.246)	-0.1249 (0.233)	-0.0219 (0.803)	-0.1122 (0.294)	-0.0897 (0.000)	-0.6213 (0.401)
Nether-lands	-0.1692 (0.005)	-0.1640 (0.007)	-0.1734 (0.003)	-0.1548 (0.001)	-0.2626 (0.000)	-0.5415 (0.022)
Norway	-0.1225 (0.004)	-0.1220 (0.004)	-0.0938 (0.029)	-0.1053 (0.000)	-0.1935 (0.000)	-0.3352 (0.215)
Ireland	-0.1972 (0.002)	-0.2003 (0.002)	-0.1939 (0.001)	-0.1853 (0.001)	-0.3140 (0.000)	-0.6048 (0.015)
Italy	-0.2132 (0.005)	-0.2081 (0.004)	-0.1784 (0.006)	-0.1869 (0.003)	-0.2574 (0.000)	-0.3305 (0.338)
Japan	-0.1542 (0.002)	-0.1170 (0.025)	-0.1385 (0.012)	-0.1391 (0.002)	-0.1940 (0.000)	-0.5348 (0.243)
Portugal	-0.2003 (0.000)	-0.1999 (0.000)	-0.1768 (0.000)	-0.1852 (0.000)	-0.2823 (0.000)	-0.4811 (0.212)
Spain	-0.2076 (0.000)	-0.2125 (0.000)	-0.1921 (0.000)	-0.1881 (0.000)	-0.2871 (0.000)	-0.4336 (0.181)
Sweden	-0.1405 (0.013)	-0.1386 (0.013)	-0.1362 (0.017)	-0.1247 (0.007)	-0.2476 (0.000)	-0.5170 (0.008)
Switzer-land	-0.1218 (0.013)	-0.1213 (0.0149)	-0.1180 (0.014)	-0.1112 (0.008)	-0.2026 (0.000)	-0.5954 (0.002)
UK	-0.1108 (0.074)	-0.1069 (0.063)	-0.1034 (0.092)	-0.0970 (0.068)	-0.2101 (0.000)	-0.4852 (0.007)
UK (in USD)	-0.2336 (0.008)	-0.2163 (0.006)	-0.2163 (0.009)	-0.2116 (0.004)	-0.3872 (0.000)	-0.6823 (0.009)

[26] We achieve very similar results for 6x9 und 9x12 Futures.

US	-0.0469 (0.048)	-0.0332 (0.215)	-0.0130 (0.548)	-0.0411 (0.046)	-0.0514 (0.000)	-0.1849 (0.151)
Average R^2	0.1121	0.1514	0.1412	0.2014	0.4152	0.0231

Notes: The reported values represent the estimated coefficient of the Brexit variable. The Newey-West estimator is used for the calculation of the covariance matrix. Estimation period: 01.04.16 – 23.06.16.

3.3.2 *Impact on long-term interest rates and sovereign credit risk*

The impact on long term interest rate ($IR10_t^i$) and sovereign credit risk (CDS_t^i). It can be expected to show a larger degree of heterogeneity across countries. In this regard, some countries might benefit from increased uncertainty, because their bonds are considered to be a safe haven in times of market turmoil.

We believe that the countries rated AAA are most likely to benefit from decreased bond yields. Table 7 presents the panel results for the 10-year interest yield. Because we assume different effects, we divide the sample into two groups: while the first group includes countries that are considered to be nearly 'risk-free' indicated by a rating of AAA, the second group includes countries that have a credit rating of below AA.[27]

Table 7. Effects on long-term interest rates ($IR10_t^i$); panel estimations

	Random Effects							
	AAA				<AA (GIIPS)			
	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
$Brexit\_Prob_t$	-0.3283 (0.000)	-0.2750 (0.000)	-0.3023 (0.000)		0.7246 (0.000)	0.7177 (0.000)	0.6991 (0.000)	
$Brexit\_Poll_t$				-0.5710 (0.000)				1.6459 (0.000)
$Future3x6_t^i$		0.4420 (0.000)				0.2412 (0.7315)		
$Comm_t$			0.3784 (0.000)				-0.5829 (0.0670)	
Pseudo R^2	0.0521	0.2022	0.0761	0.0098	0.0356	0.0360	0.0425	0.0051
Hausman p-value		0.3190					0.2151	

Note: Constants are included. P-values are presented in brackets. The Newey-West estimator is used for the calculation of the covariance matrix. Individual and time effects are included. Estimation period: 01.04.16 – 23.06.16.

We find that a one-percentage point increase in the probability of a leave vote in Britain's EU referendum leads to a decrease of about 0.3 basis points in AAA bonds, but increases interest rates of riskier countries by about 0.7 basis points. Again, our results are not driven by other developments, as indicated by the results of regressions, which include additional variables.

[27] Ratings are taken from Fitch Ratings. The AAA group contains: Canada, Denmark, Germany, the Netherlands, Norway, Sweden, Switzerland and the USA. The second group contains only the so-called GIIPS states.

Apart from the effects of Brexit probability, we obtain the surprising results that an increase in expected future interest rates increases AAA long-term yields, but it has no significant effect on yields of riskier countries.

Table 8. Effects on sovereign credit risk perception (CDS_t^i); panel estimations

	AAA				<AA (GIIPS)			
	(i)	(ii)	(iii)	(iv)	(vi)	(vii)	(viii)	(ix)
$Brexit\_Prob_t$	0.0064 (0.3847)	0.0068 (0.373)	0.0051 (0.454)		0.0923 (0.011)	0.1029 (0.002)	0.0847 (0.019)	
$Brexit\_Poll_t$				0.2127 (0.003)				0.6682 (0.015)
$Future3x6_t^i$		-0.0271 (0.278)				0.3706 (0.001)		
$Comm_t$			-0.0361 (0.064)				-0.1808 (0.001)	
Pseudo R^2	0.0191	0.0156	0.0171	0.0223	0.0117	0.0318	0.0251	0.0165
Hausman p-value		0.3521				0.9012		

Note: Constants are included. P-values are presented in brackets. The Newey-West estimator is used for calculation of the covariance matrix. Individual and time effects are included. Estimation period: 01.04.16 – 23.06.16.

Table 8 presents the panel estimation results for CDS_t^i. Overall, our results confirm differences between the two groups. When *Brexit_Prob* is used as an indicator, we find no effect on AAA countries. On the contrary, an increase in the likelihood of a Brexit vote has a significant effect on riskier countries. As presented, an increase in the probability of Brexit increases the CDS by around 0.1%. However, the results have to be interpreted with caution because our estimations explain only a small fraction of the variation in our data as indicated by the (pseudo) R^2 values.

Regarding our SUR estimation results, we observe a strong decrease in long term interest rates for the UK, of around 0.6 basis points. Similar results for the UK yield are presented by BoE (2016). With respect to the other countries, we observe the same pattern as indicated by our panel estimation results with large increases for 'riskier' countries and decreases for 'risk-free' countries. For the remaining countries which can neither be considered 'risk-free' nor high-risk (according to our classification), we observe mainly insignificant results, which further supports our argument of a safe haven effect. For Greece, we observe a very strong effect as a one-percentage point increase in the probability of a Brexit vote increases the Greek yield by 2 basis points. This does not come as a surprise as Greece has the worst rating in our sample (CCC).

The results for the sovereign credit risk reveal significant positive effects for the GIIPS countries, the UK, Germany and Belgium. While the effect on German CDS is significant it is very small as it increases by 0.05% when the probability of a Brexit vote increases by one percentage point. The largest effects are found for Italy, Spain, Greece and Portugal. Putting these results into perspective, the increases in yields appear to be driven by increases in sovereign credit risk. For the UK, we find the largest increase in CDS spreads indicating that markets assume that Brexit might have an effect on the creditworthiness of the UK.

Table 9. Effects on interest rates $IR10_t^i$ and sovereign credit risk (CDS_t^i); SUR estimation

	Specification						
	10-Year Interest Yield				CDS		
	(1)	(2)	(3)	(4)	(1)	(2)	(3)
	$Brexit\_Prob$	$Brexit\_Prob$ $Future3x6_t^i$	$Brexit\_Prob_t$ (weighted estimation)	$Brexit\_Poll_t$	$Brexit\_Prob$	$Brexit\_Prob$ $Comm_t$	$Brexit\_Poll_t$
Austria	-0.0496 (0.583)	-0.0534 (0.568)	-0.0428 (0.002)	0.6360 (0.141)	0.0355 (0.107)	0.0331 (0.114)	0.1091 (0.240)
Belgium	-0.0566 (0.591)	-0.0558 (0.596)	-0.0465 (0.0082)	-0.0036 (0.991)	0.0673 (0.000)	0.0620 (0.000)	0.2258 (0.126)
Canada	-0.5540 (0.0050)	-0.5540 (0.0050)	-0.4596 (0.0000)	-1.2151 (0.009)	0.0001 (0.452)	0.0002 (0.379)	-0.0006 (0.546)
Denmark	-0.3125 (0.0010)	-0.2505 (0.030)	-0.2595 (0.0000)	-0.4096 (0.601)	-0.0114 (0.177)	-0.0143 (0.121)	0.0084 (0.761)
Finland	-0.1609 (0.0731)	-0.1385 (0.120)	-0.0288 (0.0057)	0.3705 (0.368)	-0.0126 (0.093)	-0.0132 (0.097)	0.0938 (0.216)
France	-0.0553 (0.5614)	-0.0588 (0.544)	0.0138 (0.4286)	0.5724 (0.230)	0.0301 (0.541)	0.0245 (0.607)	0.0244 (0.814)
Germany	-0.3151 (0.0002)	-0.3125 (0.0003)	-0.2636 (0.0000)	-0.2350 (0.683)	0.0495 (0.014)	0.0499 (0.012)	0.1547 (0.339)
Greece	2.0558 (0.0427)	2.1477 (0.0480)	1.4181 (0.0000)	2.0897 (0.725)	0.1662 (0.058)	0.1635 (0.059)	0.6272 (0.322)
Nether-lands	-0.1500 (0.0758)	-0.1386 (0.132)	-0.1137 (0.0000)	0.2526 (0.573)	0.0142 (0.516)	0.0100 (0.606)	0.1727 (0.474)
Norway	-0.3544 (0.0008)	-0.1647 (0.0247)	-0.3332 (0.0000)	-0.7217 (0.408)	-0.0144 (0.382)	-0.0159 (0.330)	-0.0408 (0.161)
Ireland	0.0955 (0.5931)	0.0346 (0.875)	0.3306 (0.0000)	1.0348 (0.058)	0.0488 (0.014)	0.0408 (0.092)	-0.2553 (0.561)
Italy	0.3450 (0.0851)	0.3324 (0.118)	0.6338 (0.0000)	1.0200 (0.076)	0.1982 (0.009)	0.1832 (0.006)	0.9263 (0.235)
Japan	-0.1334 (0.0722)	-0.2013 (0.0211)	-0.0567 (0.0000)	-0.3063 (0.020)	0.1730 (0.221)	0.1670 (0.235)	0.2501 (0.645)
Portugal	0.8974 (0.0084)	0.8931 (0.011)	1.4330 (0.0000)	2.4518 (0.055)	0.1561 (0.039)	0.1444 (0.046)	0.2880 (0.674)
Spain	0.3989 (0.0261)	0.4053 (0.033)	0.6732 (0.0000)	1.3719 (0.060)	0.1578 (0.000)	0.1489 (0.000)	0.1983 (0.630)
Sweden	-0.3199 (0.0070)	-0.3265 (0.004)	-0.3153 (0.0000)	-0.5805 (0.275)	-0.0028 (0.742)	-0.0049 (0.502)	0.0319 (0.614)
Switzer-land	-0.2456 (0.0270)	-0.2458 (0.028)	-0.3398 (0.0000)	-0.8675 (0.200)	-0.0008 (0.339)	-0.0005 (0.475)	-0.0067 (0.146)
UK	-0.6039 (0.0000)	-0.5047 (0.0000)	-0.7194 (0.0000)	-1.5587 (0.067)	0.2109 (0.031)	0.2135 (0.027)	0.9386 (0.060)
United	-0.4241	-0.2093	-0.4281	-1.0500	0.1303	0.1456	0.7226

States	(0.001)	(0.0149)	(0.0015)	(0.026)	(0.326)	(0.300)	(0.287)
Average R^2	0.0645	0.2224	0.3521	0.0098	0.0143	0.0254	0.0253

Note: The reported values present the coefficient of the Brexit variable. The Newey-West estimator is used for the calculation of the covariance matrix. Estimation period: 01.04.16 – 23.06.16.

3.3.3 Impact on the external value of the British pound

Because Brexit can be linked to uncertainty and the possibility of an economic decline in the UK in the future, an increase in the likelihood of a Brexit vote should cause a depreciation of the British pound. This hypothesis is supported by large losses of the pound vis-à-vis other currencies on the day after the referendum.

However, the exchange value is not only linked to expectations about the development of real economic variables and the level of uncertainty, but also with interest rate differentials and expectations about (national) monetary policies.[28] In order to account for these aspects, we calculate the difference between the three-month future of country *i* and the value for the UK ($\mathrm{Future3x6}_t^i - \mathrm{Future3x6}_t^{UK}$). We follow the same approach to calculate the (long-term) interest rate differential.

Table 10. Effects on the external value of the British pound ExR_t^i; panel estimations

	Random Effects					
	(i)	(ii)	(iii)	(iv)	(v)	(ii)
$Brexit\_Prob_t$	-0.1217 (0.000)	-0.1183 (0.000)	-0.1118 (0.000)			
$Brexit\_Poll_t$				-0.2306 (0.000)	-0.2100 (0.000)	-0.2063 (0.000)
$Diff\_Future3x6_t^i$		-0.0557 (0.000)			-0.0551 (0.000)	
$Diff\_IR10_t^i$			-0.0331 (0.000)			-0.0342 (0.000)
Pseudo R^2	0.1731	0.1788	0.1862	0.0148	0.0314	0.0517
Hausman-test *p*-value		0.4998	0.5062		0.7213	0.7009

Note: Constants are included. P-values are presented in brackets. The Newey-West estimator is used for the calculation of the covariance matrix. Individual and time effects are included. Estimation period: 01.04.16 – 23.06.16.

According to our panel estimation results, a one-percentage point increase of the probability of a Brexit vote decreases the value of the pound by around 0.12%. When we focus our analysis on poll survey data (*Brexit_Poll*), the effect is about 0.23%. For our control variables, we find the expected impact of the interest rate differentials.

[28] In case of the euro, we take German 10y yields as a proxy of the 'European' interest rate. However, we do not find different results when Dutch, French or Finnish Yields are used.

Table 11. Effects on the external value of the British pound ExR_t^i; SUR estimations

	Specification				
Exogenous Variables:	(1) $Brexit\_Prob_t$	(2) $Brexit\_Prob_t$ $Diff\_Future3x6$	(3) $Brexit\_Prob_t$ $Diff\_IR10_t^i$	(4) $Brexit\_Prob_t$ (weighted estimation)	(4) $Brexit\_Poll_t$
Canadian dollar	-0.1115 (0.001)	-0.1108 (0.001)	-0.1115 (0.001)	-0.1451 (0.000)	-0.2007 (0.209)
Danish dkrone	-0.1057 (0.000)	-0.1032 (0.000)	-0.1059 (0.000)	-0.1370 (0.000)	-0.2115 (0.157)
Euro	-0.1055 (0.000)	-0.1021 (0.001)	-0.1051 (0.000)	-0.1367 (0.000)	-0.2082 (0.166)
Norwegian krone	-0.0543 (0.109)	-0.0522 (0.119)	-0.0605 (0.069)	-0.0664 (0.000)	-0.1045 (0.421)
Japanese yen	-0.1584 (0.000)	-0.1381 (0.000)	-0.1434 (0.002)	-0.2006 (0.000)	-0.1728 (0.581)
Swedish krone	-0.0865 (0.005)	-0.0918 (0.005)	-0.0797 (0.016)	-0.1233 (0.000)	-0.2995 (0.035)
Swiss franc	-0.1316 (0.000)	-0.1285 (0.001)	-0.1297 (0.000)	-0.1784 (0.000)	-0.3629 (0.041)
US dollar	-0.1228 (0.001)	-0.1220 (0.001)	-0.1283 (0.000)	-0.1772 (0.000)	-0.2848 (0.159)
Average R^2	0.3321	0.2356	0.2252	0.3542	0.0142

Notes: The reported values present the coefficient of the Brexit variable. The Newey-West estimator is used for the calculation of the covariance matrix. Estimation period: 01.04.16 – 23.06.16.

Regarding the effect on the value of the British pound, we find similar results across currencies. The weakest and sometimes insignificant effect is found for the Norwegian krone. Again, when we account for the timing of the probability increase by weighting the observations, we find larger and very significant results. For the euro, we find an appreciation of up to 0.14% against the British pound. For the USD, we find even stronger effects of up to 0.1772%.

Comparing our results to the exchange rate development immediately after Brexit on Friday, June 24th, the British pound depreciated against the USD (euro) by around 8 (6.3)%. The probability of Brexit on June 23rd was about 17%. Calculating 83 * 0.1021 = 8.476 for the euro and 83 * 0.1220 = 10.126 for the USD, we obtain estimates that are quite close to the observed developments.

In order to check the robustness of our results, we perform several additional estimations. We estimate (G)ARCH models to correct for a potential volatility cluster, which can be frequently observed in financial markets. However, our models do not find evidence of (G)ARCH effects. For the estimation of the stock market impacts, we use a different sample based on MSCI data. We find nearly identical results. We also use six-month and nine-month futures instead of the three-month interest rate and obtain nearly identical results.

Comparing our results with those presented by Krause et al. (2016), we find qualitatively similar results. Although results cannot be compared quantitatively due to differences in the variables used to measure the probability of Brexit,[29] it is worth mentioning that Krause et al. (2016) find strong effects on stock prices, government bond yields and the British pound. However, while the authors find significant effects for the UK, impacts on German, European and US variables are significantly smaller and in most cases insignificant. Another study by Arnorsson and Zoega (2016) finds a (very) strong effect on the British pound. Based on their results, a one-percentage point increase in Brexit polls towards 'leave' lowers the external value of the pound vis-à-vis the euro by 1.1%. As both studies are based on poll data, the differences might be caused by differences in the exogenous variables. However, the results suffer from a weak amount of explanatory power, as indicated by the R^2 of their estimations.

Gerlach and Di Giamberardino (2016) use an approach that is related to ours; but they restrict their estimations to the effects on the British pound (we include more countries and their exchange rates) and do not correct for expectations of future monetary policy, as we do. They find that an increase of one percentage point in the probability of Brexit depreciates the pound against the USD by about 0.21%. Our results point in the same direction but are somewhat smaller (around 0.12%). Regarding the effects on stock prices, Raddant (2016) focuses on the immediate impact after the referendum. While he also observes strong negative effects on European stock markets, he concludes that the Italian stock market is highly affected by Brexit, despite a relatively low connection between both markets. His result is corroborated by our estimations. However, we observe a similar pattern for Portugal and Spain as well.

Regarding the most recent developments in equity markets in Europe, we have observed a relatively strong recovery after the EU-referendum in the UK. For example, the Stoxx Europe 600 was priced at around 346 points before Brexit and subsequently decreased by about 11%. On 22 September 2016, the index was again at 347 points. Some authors assess the development by stating that the effects of Brexit have already vanished. We argue that the recovery of prices does not indicate that the Brexit vote had only a small or no effect. First of all, stock prices are assumed to follow a random walk. Therefore, past shocks – like the Brexit vote – still have an effect on current prices. Furthermore, stock prices are highly information-efficient. As new information is priced in, the new (good) news might (over-)compensate the effects of past news. As we do not know the counterfactual i.e. the equity price development without Brexit, we cannot state that Brexit effects have already vanished by simply observing recent price developments.

4. Conclusions

In this paper, we assessed the impact of Brexit uncertainty on the UK and also on international financial markets, for the first and the second statistical moments. Firstly, we estimated the time-varying interactions between UK policy uncertainty, which can to a large extent be attributed to uncertainty around the Brexit vote, and UK financial market volatilities (second statistical moment) and identified the substantial role of policy uncertainty for financial market volatilities. The policy uncertainty induced by the Brexit referendum resulted in huge spillovers to financial markets, with magnitudes that had never been observed before. Moreover, the policy uncertainty spillovers have remained strong

[29] The authors use poll results from *whatukthinks.org* in order to construct a dummy variable for time periods when the support for leave exceeds the support for remain.

since then, suggesting that political uncertainty concerning the development of the relationship between the UK and the EU causes turbulence on financial markets, even three months after the vote. This can further weaken investment and hiring in the UK, and the rest of Europe. On the whole, we thus feel legitimised to corroborate the view of the IMF (2016) and others that Brexit-caused policy uncertainty will continue to cause instability in key financial markets and has the potential to do damage to the British (and, as shown in section 4, other European countries') real economy as well, even in the medium run.

Secondly, we used two other measures of the perceived probability of a Brexit vote, namely daily data between 1st April and 23rd June 2016 of probabilities released by Betfair as well as (aggregated) results of polls published by Bloomberg. Based on these datasets, we analysed the Brexit effect on the levels of stock returns, sovereign CDS, 10-year interest rates in 19 different predominantly European countries as well as the British pound and the euro (first statistical moment). Here, we find evidence that an increase in the probability of Brexit has especially strong effects on European stock markets.

Regarding the effect on long-term interest rates and CDS, we observe a large heterogeneity across countries, which can be related to the differences in sovereign credit risk. The main cause of this pattern might be related to an expected decrease in economic activity that might further jeopardise the sustainability of government debt. As Brexit might have unforeseeable effects on the stability of the entire EU, the effects may simply be generated by an increase in, according to our view, the still low probability of a breakup of the euro area or the EU. Regarding the effect on the exchange rate, we found that an increase in the probability of a Brexit vote led to a depreciation of the British pound. Based on the results gained in our paper, the main losers outside the UK appear to be the GIIPS economies, which are still struggling with the legacy of the sovereign debt crisis. How, then, should we explain the current lack of an even bigger (real economic) impact? It may just be because Brexit has not happened yet.

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Appendix

Table A1. VAR model specification tests

VAR Lag Order Selection Criteria
Included observations: 4096

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-5628.419	NA	0.003139	2.749716	2.754344	2.751355
1	13690.21	38599.53	2.52e-07	-6.678814	-6.660304*	-6.672260
2	13725.84	71.13829	2.49e-07	-6.691817	-6.659426	-6.680349*
3	13735.18	18.62615	2.49e-07	-6.691981	-6.645708	-6.675598
4	13754.55	38.61553	2.48e-07	-6.697044	-6.636889	-6.675746
5	13767.38	25.56895*	2.47e-07*	-6.698916*	-6.624880	-6.672704
6	13772.96	11.11774	2.48e-07	-6.697248	-6.609330	-6.666121
7	13779.73	13.45019	2.48e-07	-6.696155	-6.594355	-6.660113
8	13787.36	15.17536	2.48e-07	-6.695488	-6.579807	-6.654532

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

Roots of Characteristic Polynomial
Lag specification: 1 5

Root	Modulus
0.990123	0.990123
0.983251	0.983251
0.958368	0.958368
0.348462 - 0.447724i	0.567346
0.348462 + 0.447724i	0.567346
0.289396 - 0.381579i	0.478908
0.289396 + 0.381579i	0.478908
-0.336782 - 0.271603i	0.432655
-0.336782 + 0.271603i	0.432655
-0.415378	0.415378
0.055904 - 0.393290i	0.397244
0.055904 + 0.393290i	0.397244
-0.290021 - 0.259796i	0.389366
-0.290021 + 0.259796i	0.389366
0.349733	0.349733

No root lies outside the unit circle.
VAR satisfies the stability condition.

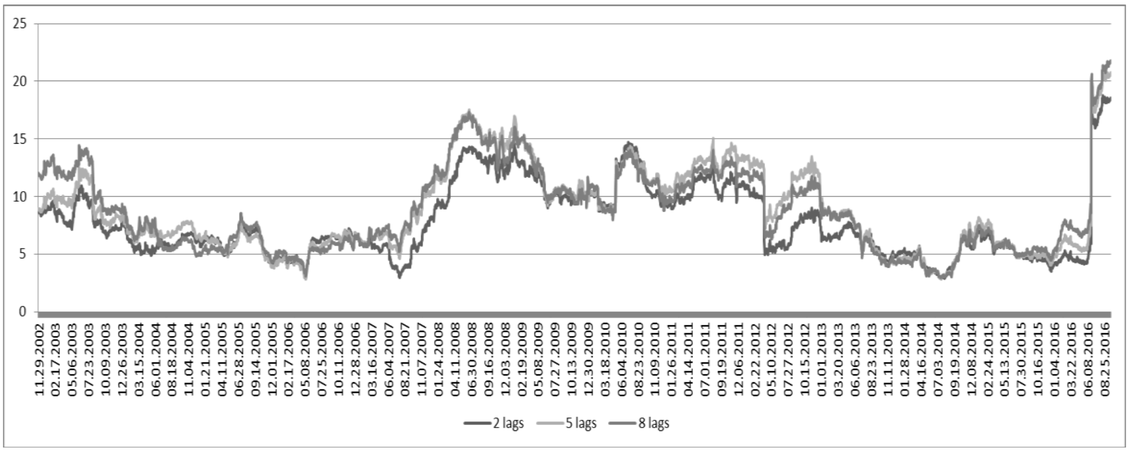
VAR Residual Serial Correlation LM Tests
Included observations: 4099

Lags	LM-Stat	Prob
1	6.356161	0.7038
2	5.070791	0.8281
3	9.175463	0.4212

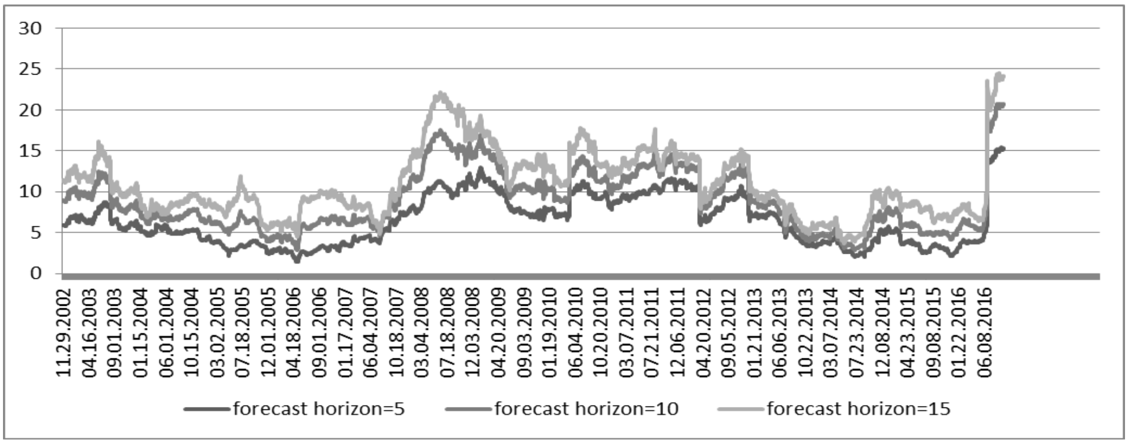
Probs from chi-square with 9 df.

Figure A1. Robustness Check[30]

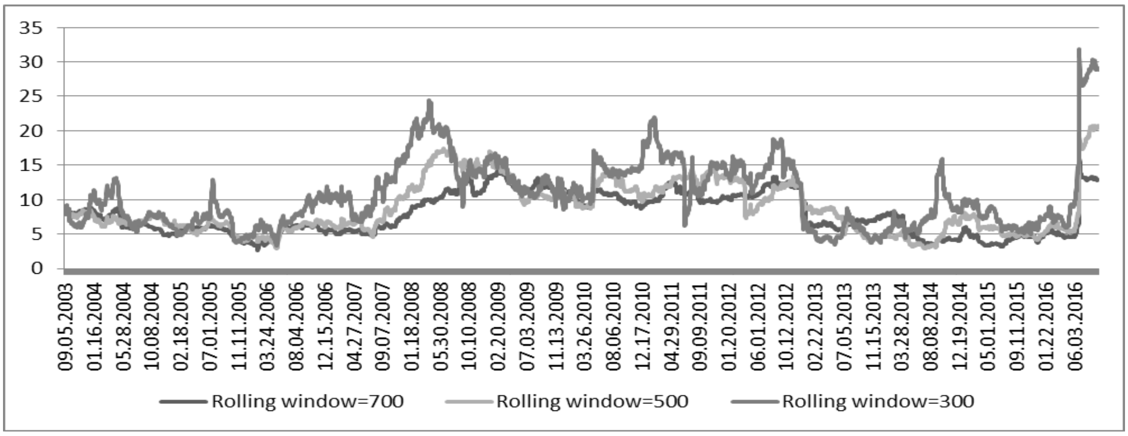
a) *Total Spillover Index for different lag choices*



b) *Total Spillover Index for different forecast horizon choices*



c) *Total Spillover Index for different rolling window choices*



[30] Additional robustness check results for other spillover indices are available upon request.